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Surveillance Test Articles Development

January 2024

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Changing the World's Energy Future

Idaho National Laboratory

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Surveillance Test Articles Development

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January 17, 2024

Overview Of Previous Work at ANL

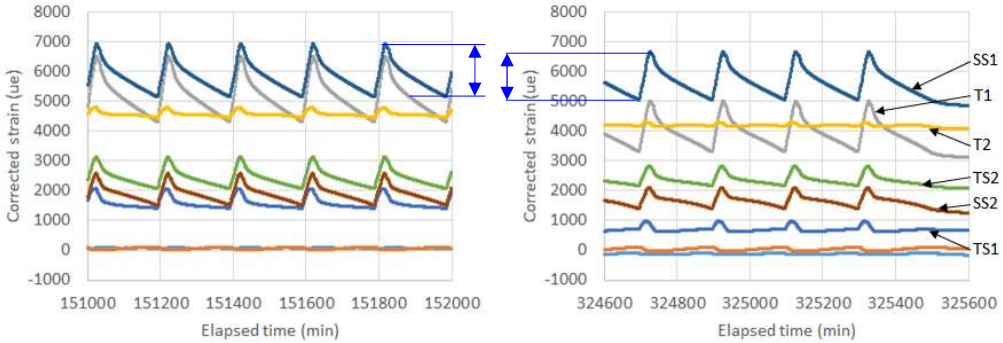
Large specimens

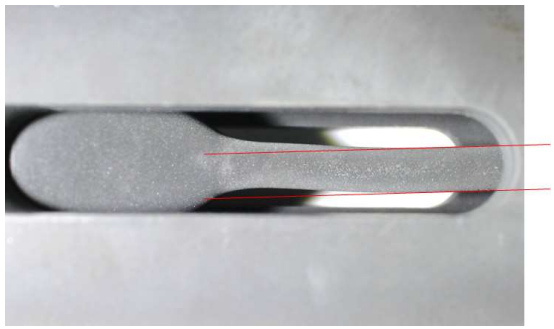
Small specimens

- **Initial designs tested with A617 driver**
- **3 families of specimens**
  - Large: demonstrate failure during test
  - Small: demonstrate realistic-sized samples
  - Reference: to validate the strain-gauge thermal strain correction
- **Thermal cycling between 500 and 650℃, over a period of about 200 minutes**

Overview Of Previous Work at ANL Contd.

- Demonstrated basic surveillance approach
- Large specimens failed in gauge section
- The bimetallic welds appeared intact at the end of testing (316H-A617)
- Gradual decrease in strain range over time
- Strain gauge reliability was an issue: at least one gauge failed
- Failure mode (buckling) was not what we had expected

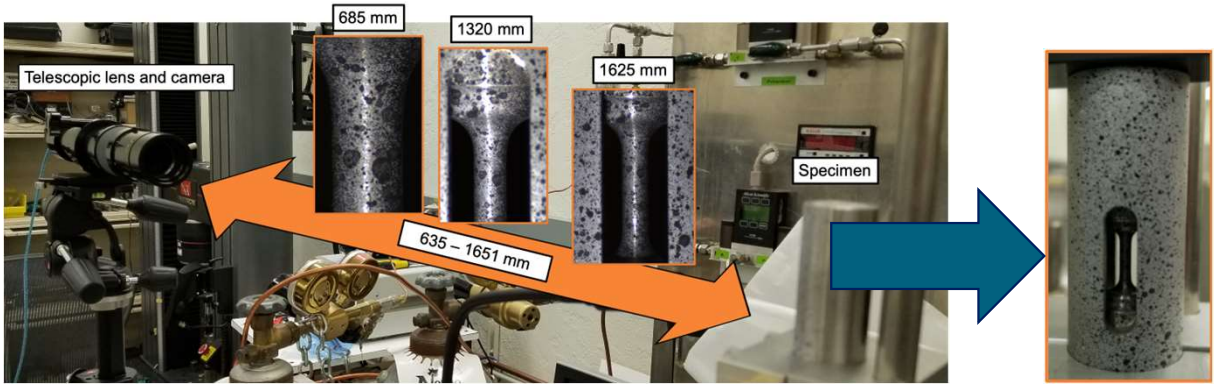


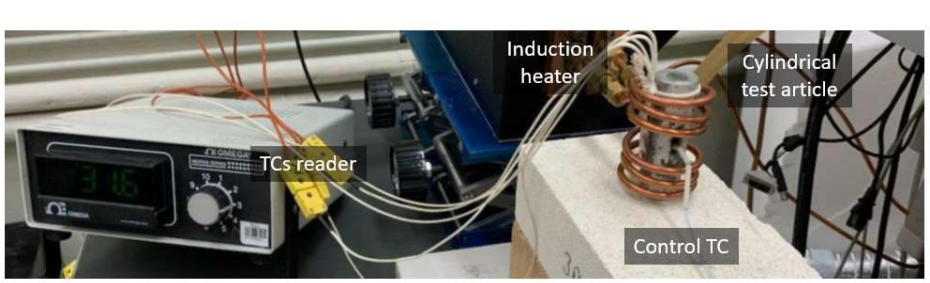


Buckling deflection

Overview Of Previous Work at INL

- Induction heating setup with DIC
- Speckle pattern
- Optimization of DIC setup
- Specimen design not suitable for induction heating

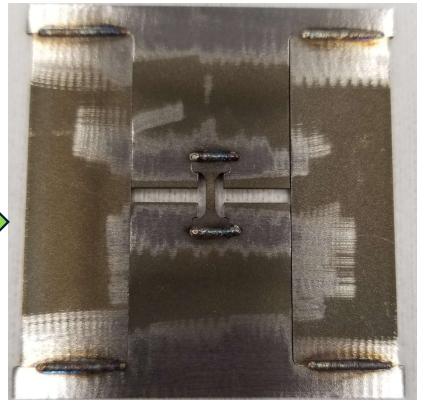




Surveillance Test Article – Development History

Large test articles
300 mm long
25 mm diameter

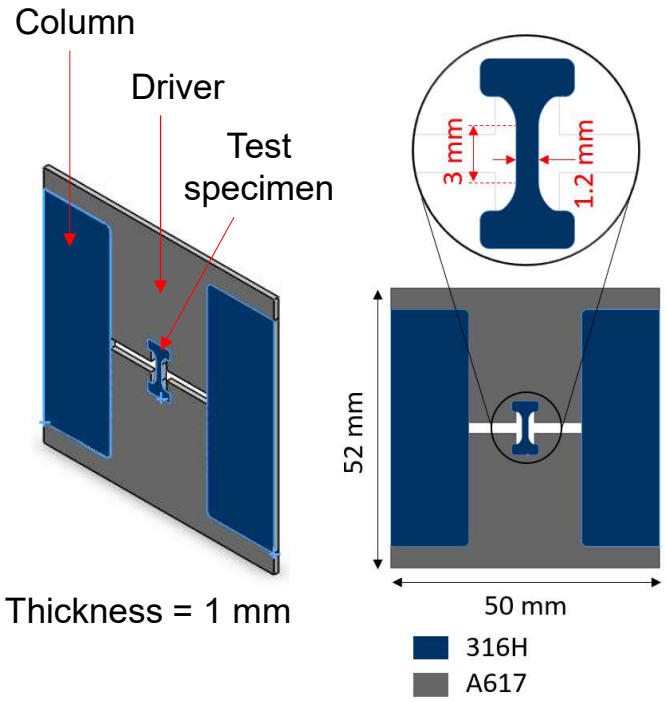
Small test articles
75 mm long
25 mm diameter



Flat test articles
52x50x1 mm

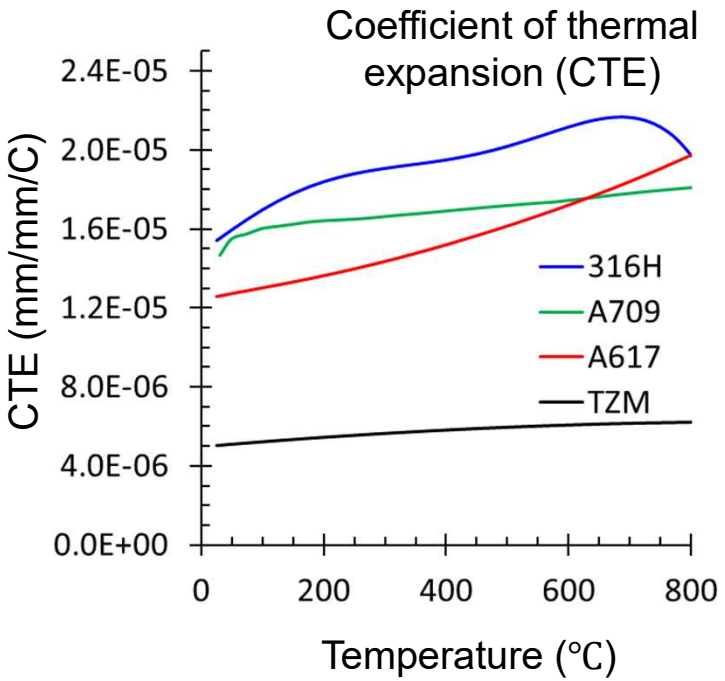
New Surveillance Test Article

- Easier to manufacture
- Easier to instrument and monitor during the validation
- Smaller and less disruptive to fluid flow/plan operation
- Design is more accessible for evaluation and mechanical testing after the test articles are removed from the reactor; also, smaller activated volume



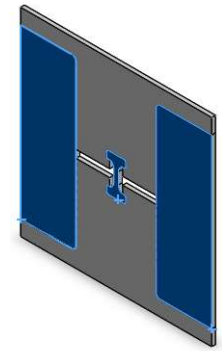
Selected Materials For Thermal Mismatch

- **First sample set –**
  - 316H as test material
  - A617 as a driver material
- **Second sample set –**
  - A709 as test material
  - TZM as a driver material

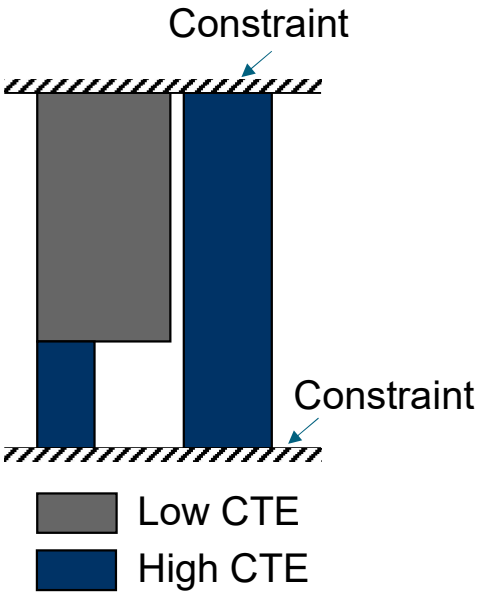


Test Article Design Approach

1. Initial design with a three-bar model approach with target strain range and elastic follow-up
2. Detailed geometry optimization with a Finite-Element analysis



Test article



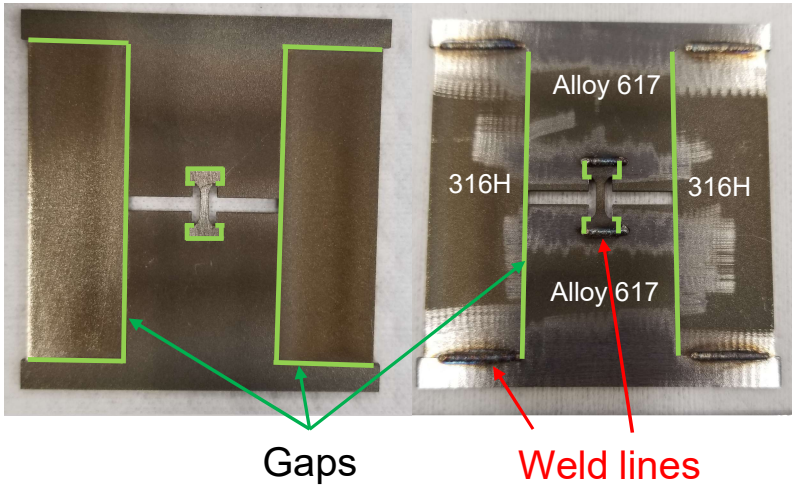
Equivalent Three bar model

Test Article Fabrication

Welded test article

Pre-weld test article assembly

Welded test article

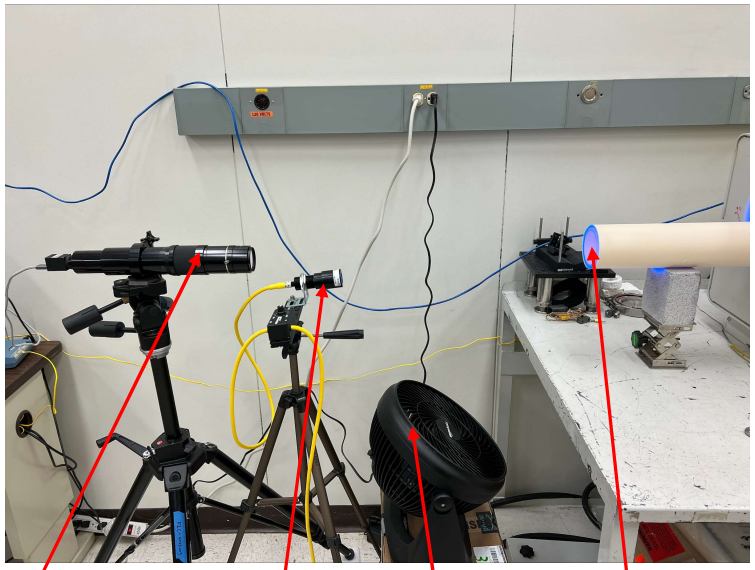


Interlocking test article

Test article assembly

Furnace Heating and DIC Setup

Digital Image Correlation (DIC)



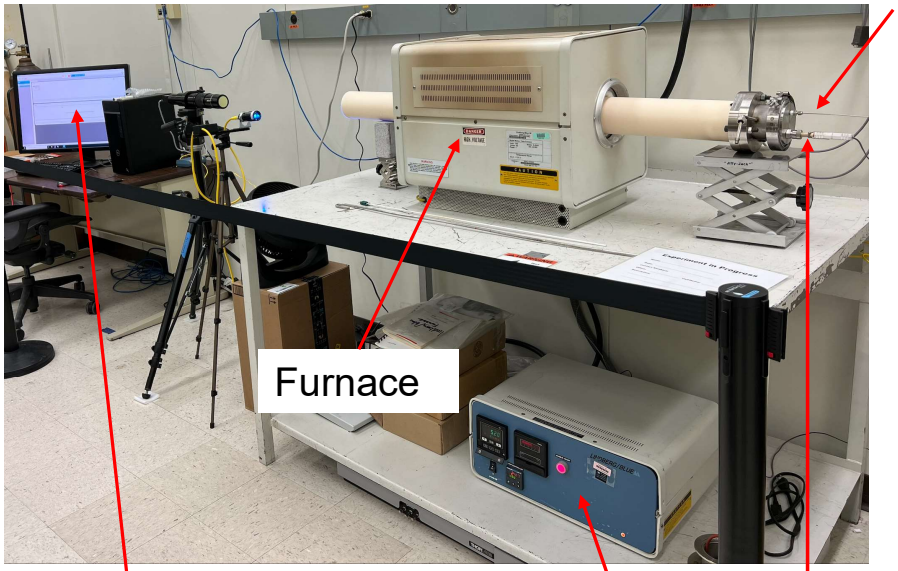
Camera + Blue light filter

Blue light

Fan

Quartz glass window

Furnace heating setup



Monitoring thermocouple

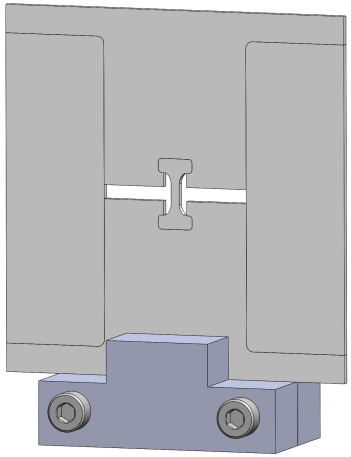
Data and image acquisition system

Furnace controller

Furnace control Thermocouple

Specimen Holder

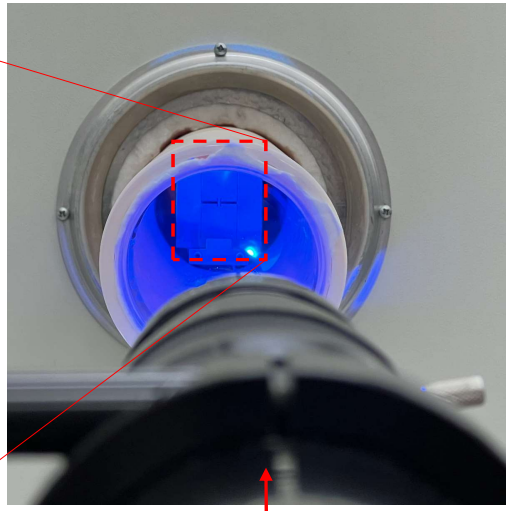
Design of Specimen + holding fixture



Interlocking Specimen + holding fixture

Welded Specimen + holding fixture

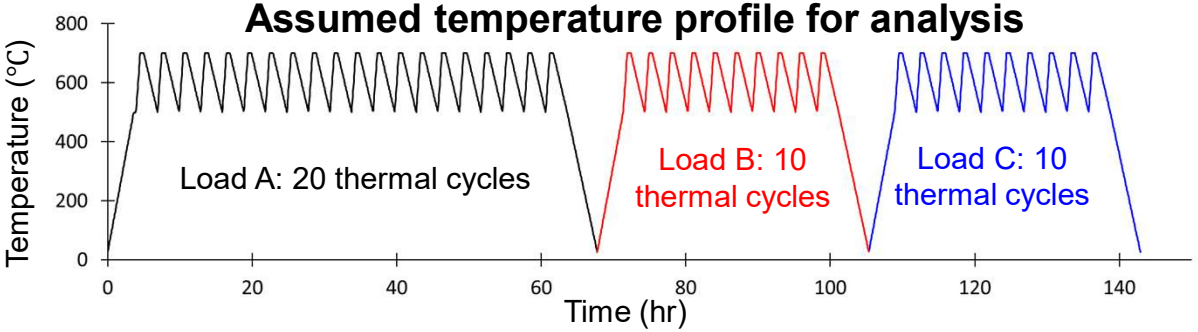
View of test article



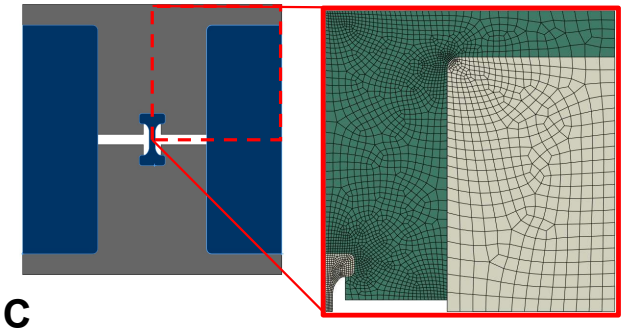
Camera + Blue light filter

Test Article Analysis Results

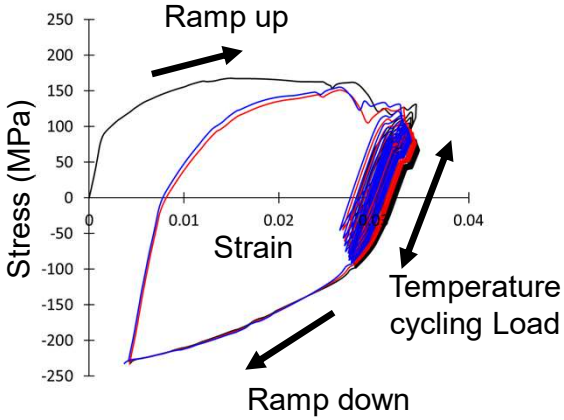
Assumed temperature profile for analysis



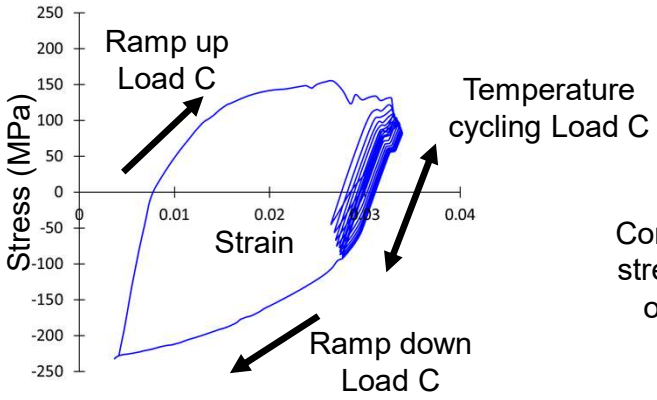
Finite Element Analysis

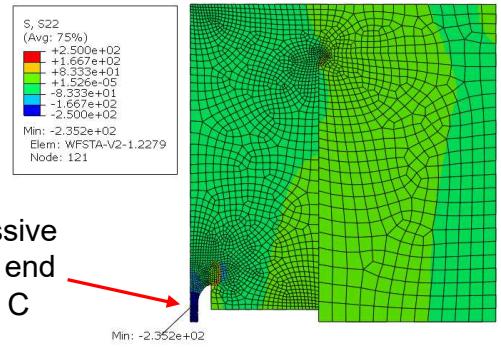


Stress-strain response



Stress-strain response of Load C





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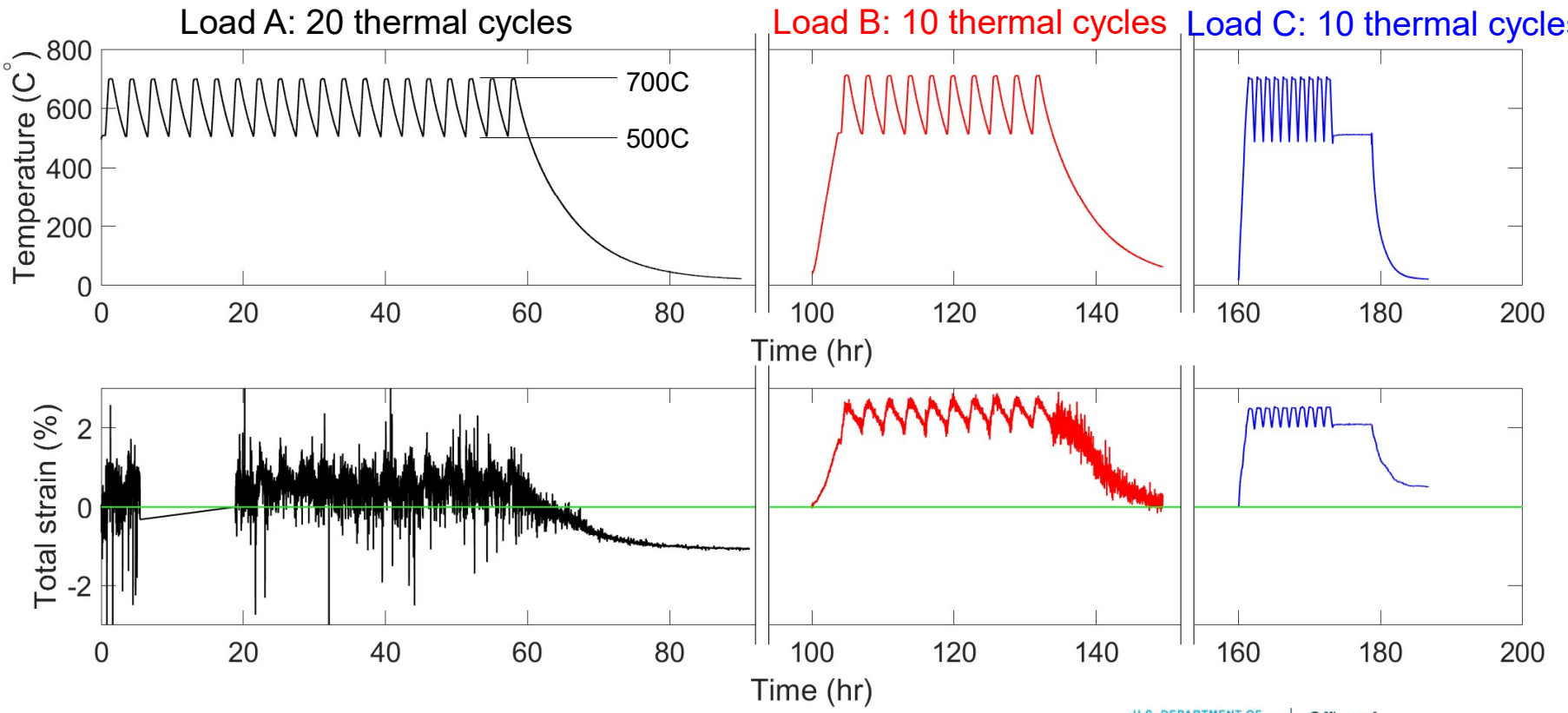
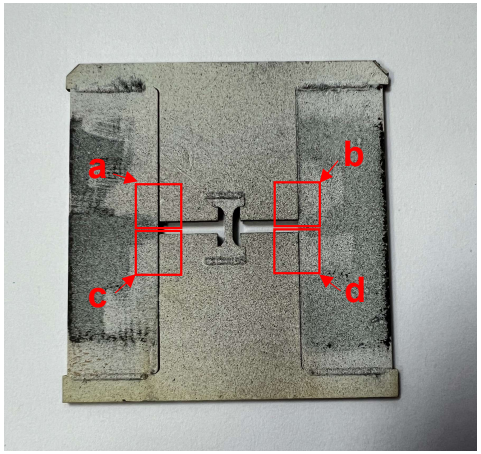
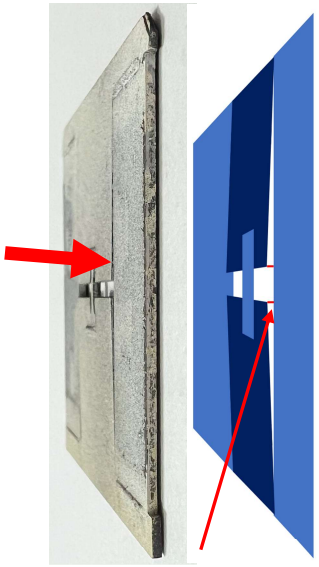
Thermal Cycling Of Welded Sample



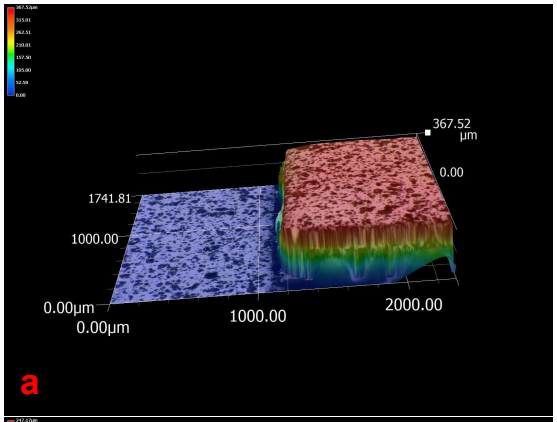
Bending Of Sample After Load A

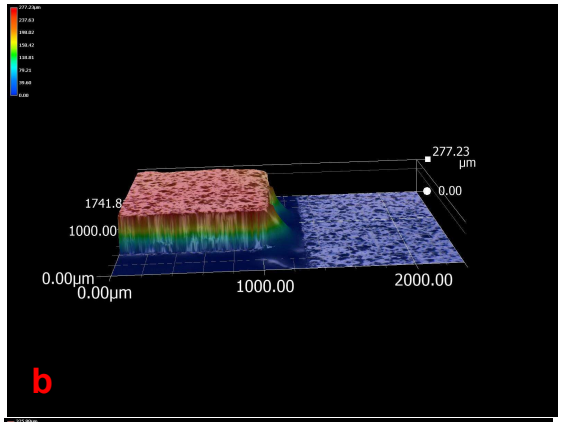
Out-of-plane bending

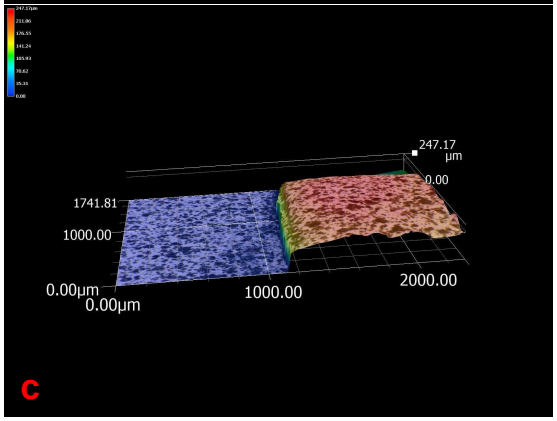


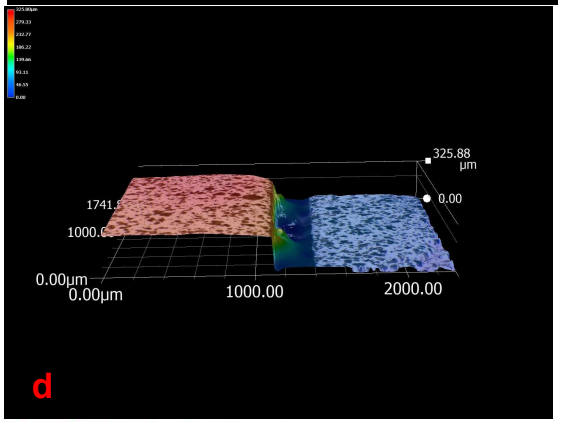


Schematic figure highlighting bending

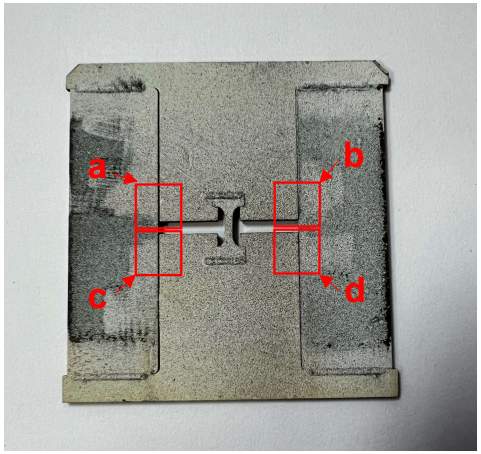


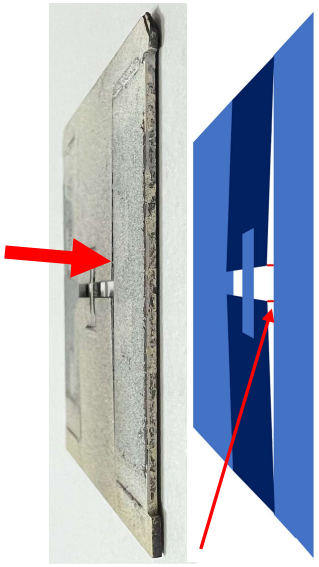




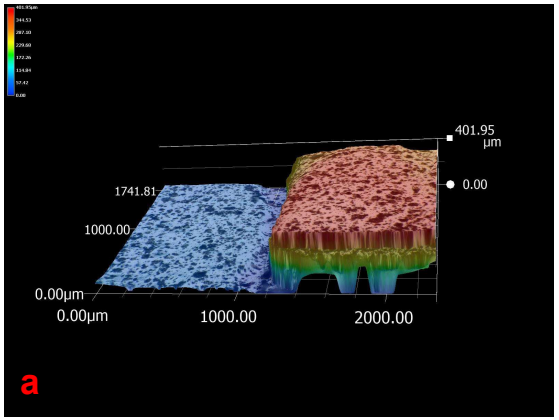


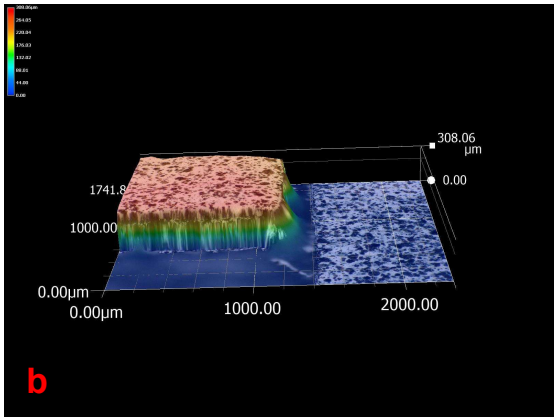
Bending Of Sample After Load B

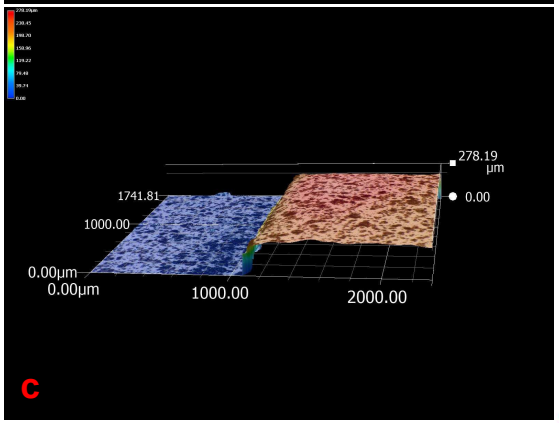


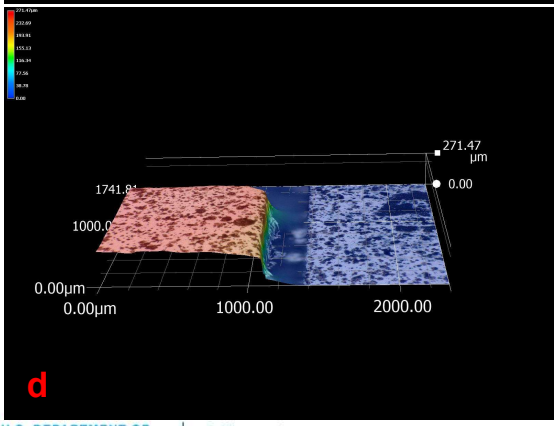


Schematic figure highlighting bending

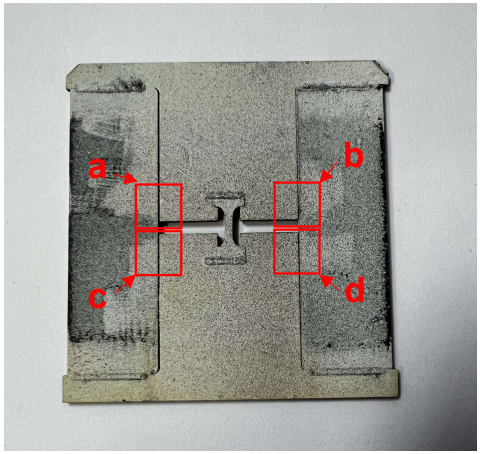


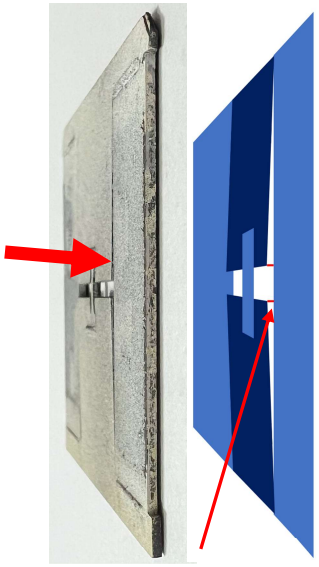




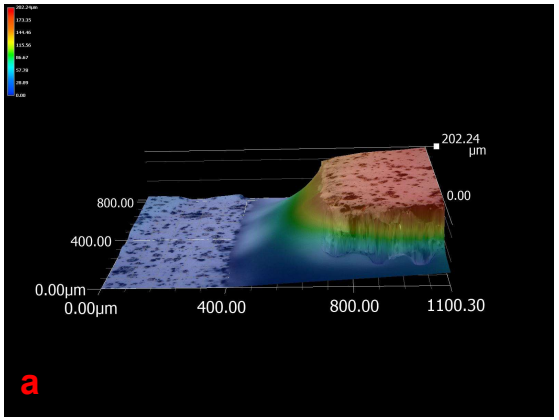


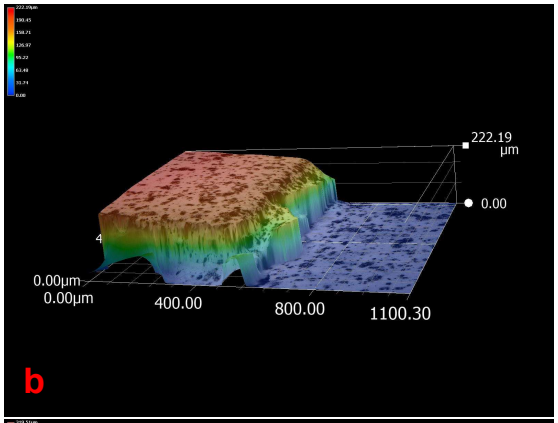
Bending Of Sample After Load C

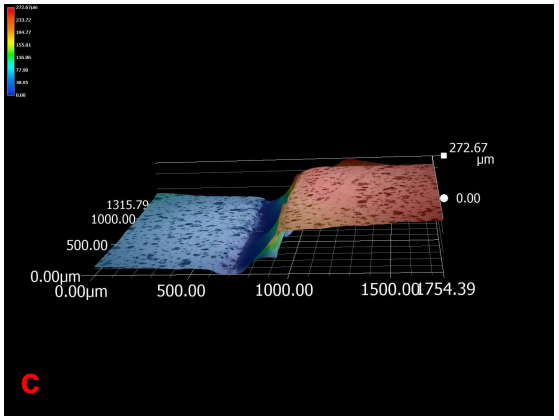


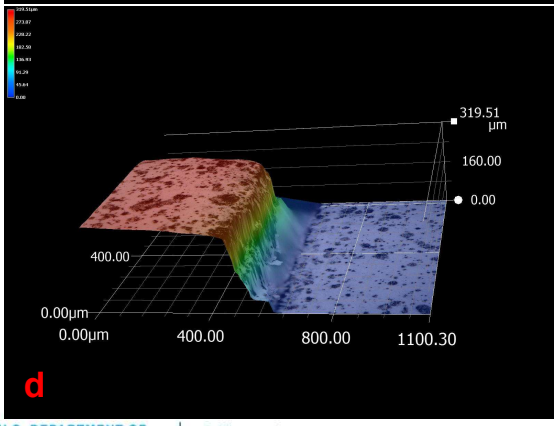


Schematic figure highlighting bending

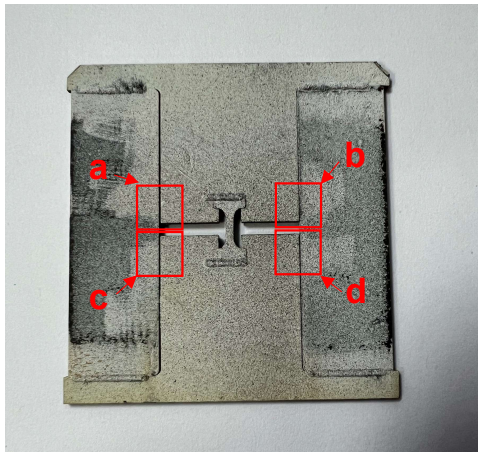


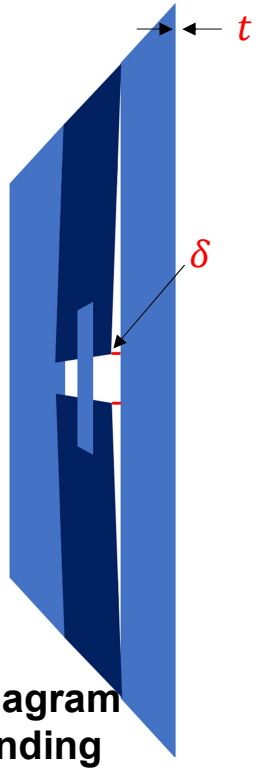






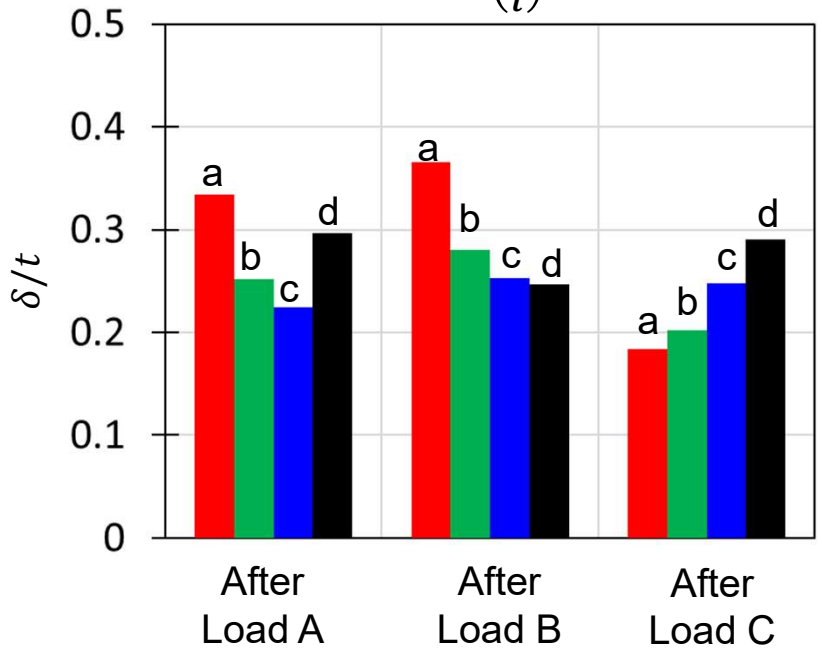
Out-of-plane Bending of Sample





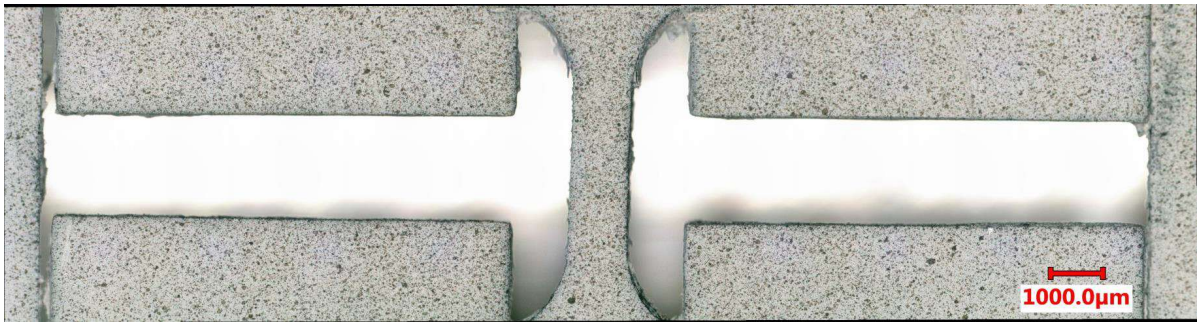
Schematic diagram showing bending

Normalized out-of-plane deformation at the end of each load $\left(\frac{\delta}{t}\right)$ at four points

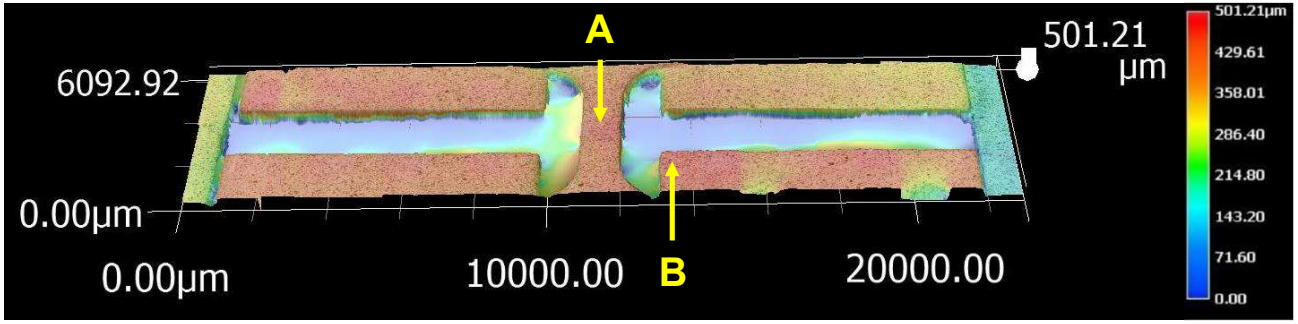


Out-of-plane Bending of Sample Contd.

2D overview of the test article



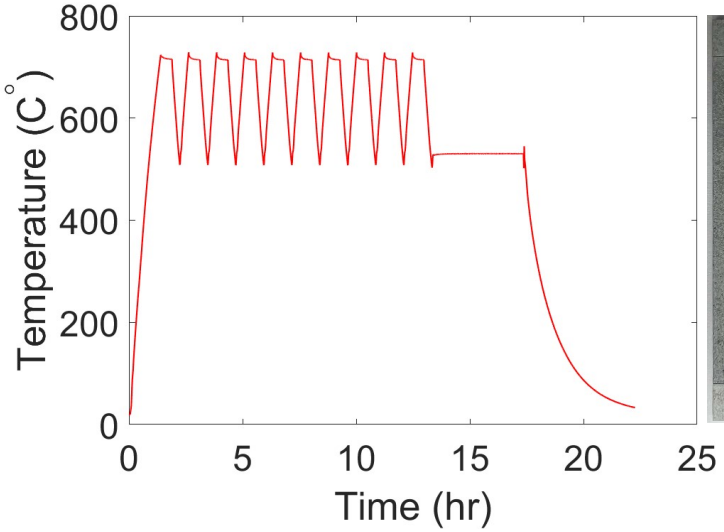
Contour plot showing out of plane deformation of test article



Out of plane deformation

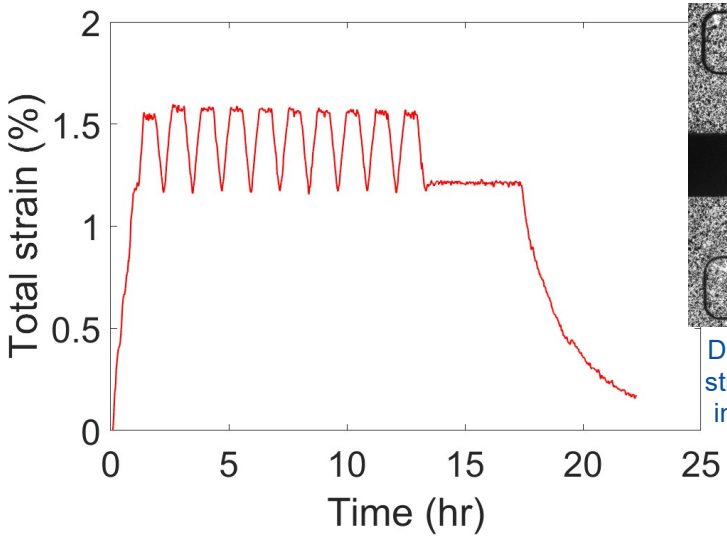
Thermal Cycling Of Interlocking Sample

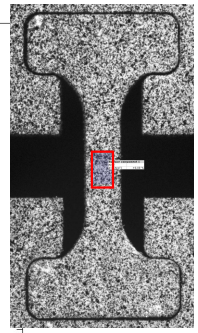
Temperature history



Specimen

Measured strain profile

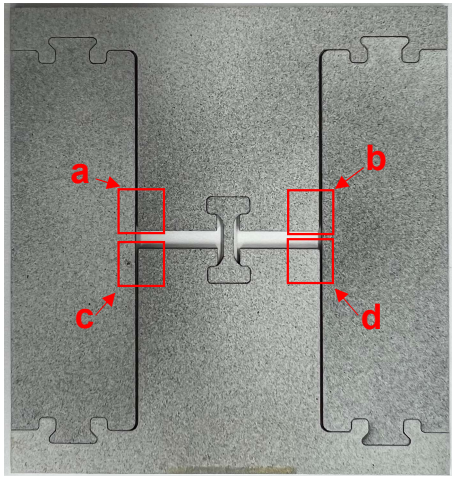


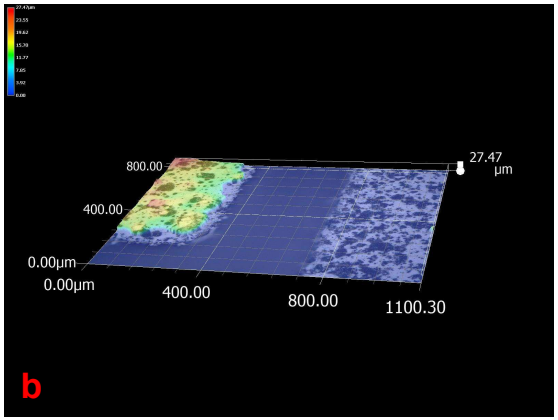


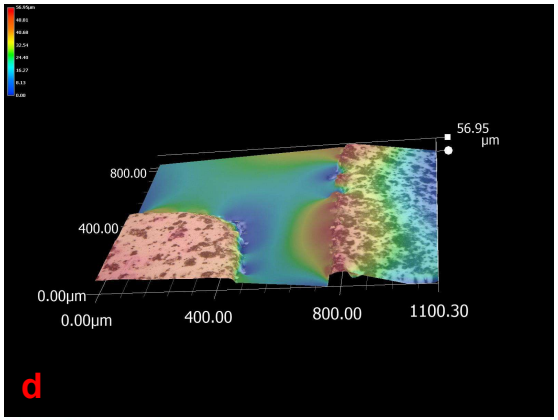
DIC area for strain history information

Bending Of Interlocking Sample

- Negligible bending after final cooldown
- Specimen could be removed from the test article for post-test non-destructive evaluation and reloaded back in the test article

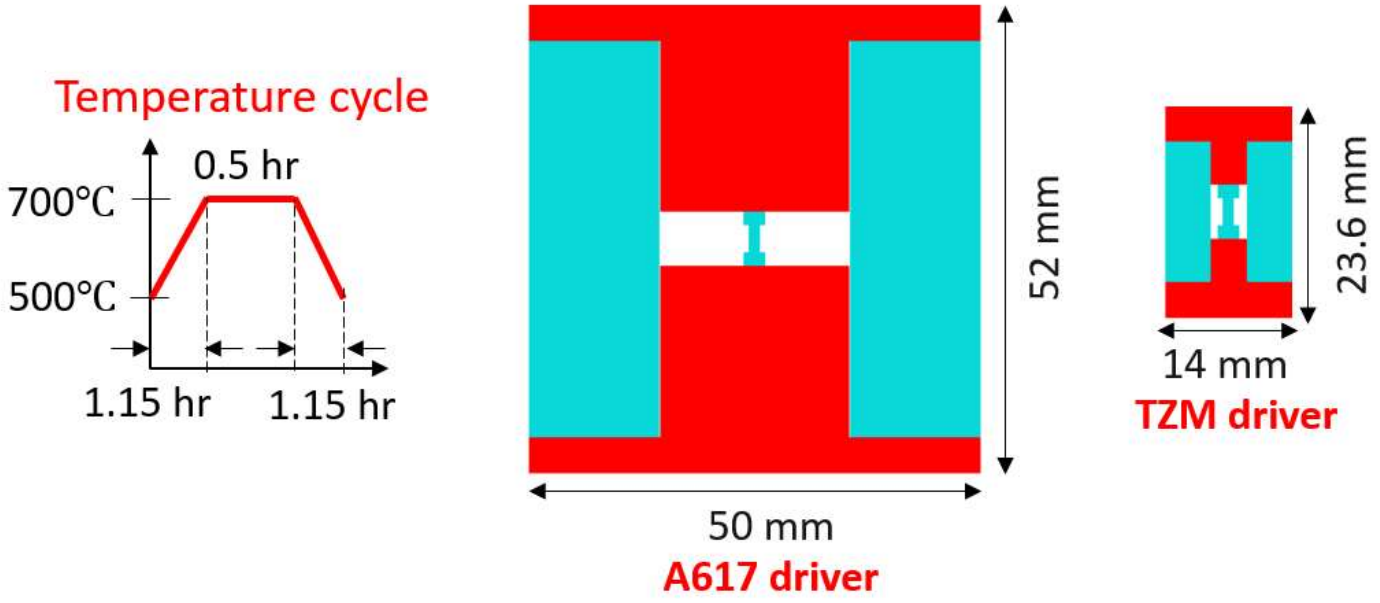






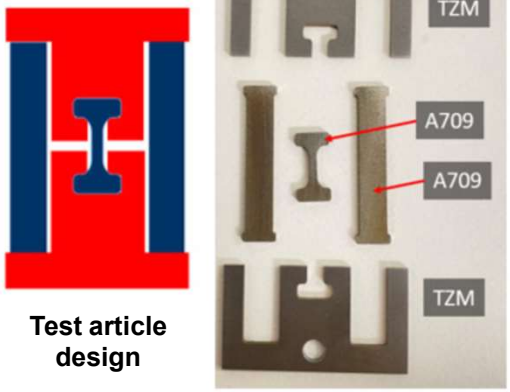
Interlocking Sample Design With Higher Thermal Mismatch

Schematic figure showing influence of driver material with larger expansion coefficient mismatch



Interlocking Sample Design With TZM And A709

Interlocking TZM sample fabrication approach

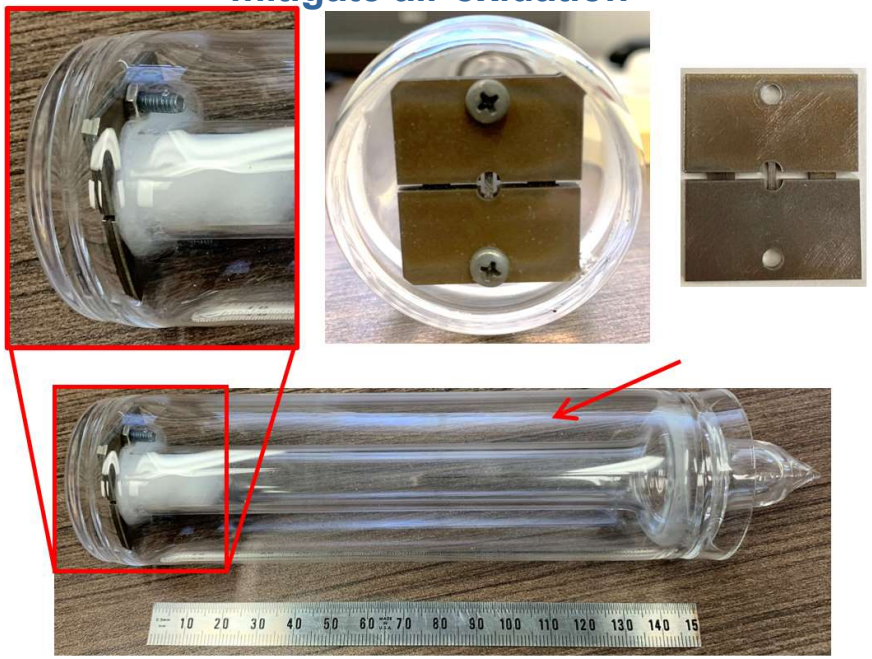


Test article design

Interlocking assembly

Assembly with top and bottom cover plates

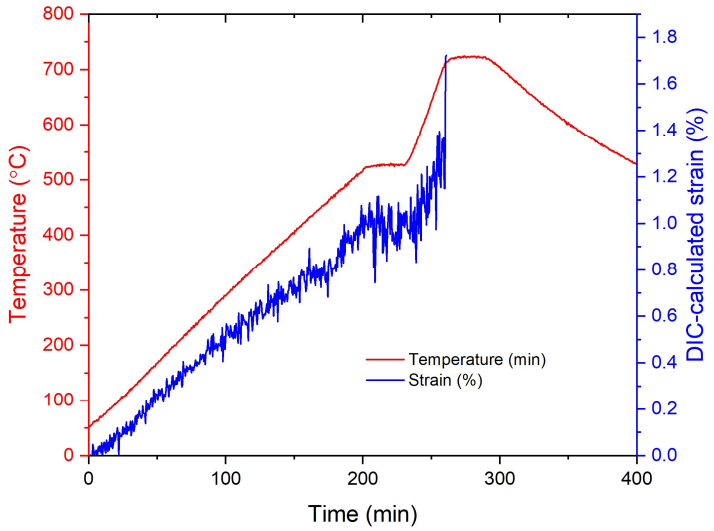
Glass enclosure for TZM samples to mitigate air oxidation



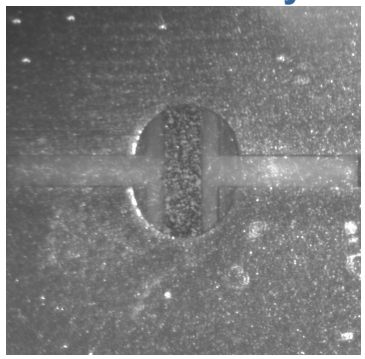
Interlocking Sample Design With TZM And A709

- Test assembly in furnace
- Speckles applied using high temperature paint were destroyed at higher temperature
- Development of LASER engraving technique is in progress

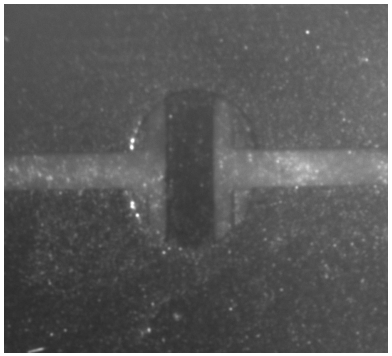
Temperature history and strain profile



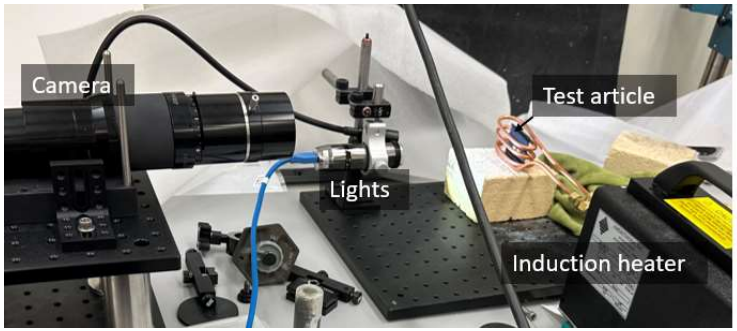
Before thermal cycling

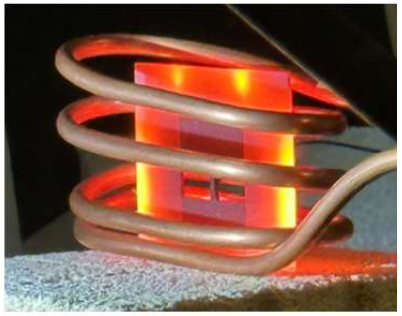


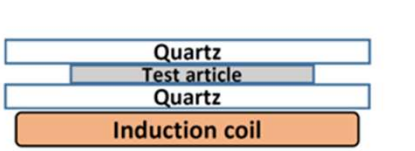
After thermal cycling

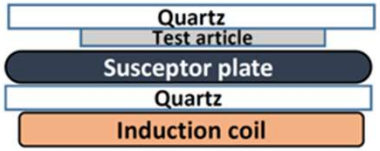


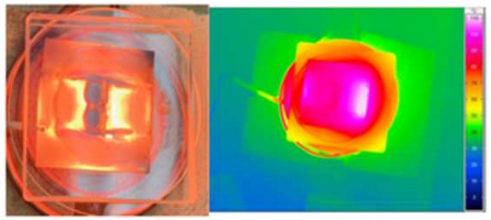
Induction Heating Setup – Lessons Learned





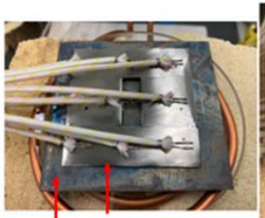






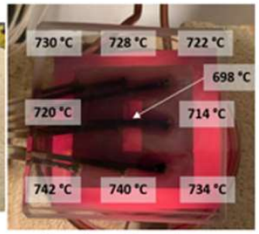
Heating of specimen

Temperature distribution



Test article

Susceptor plate

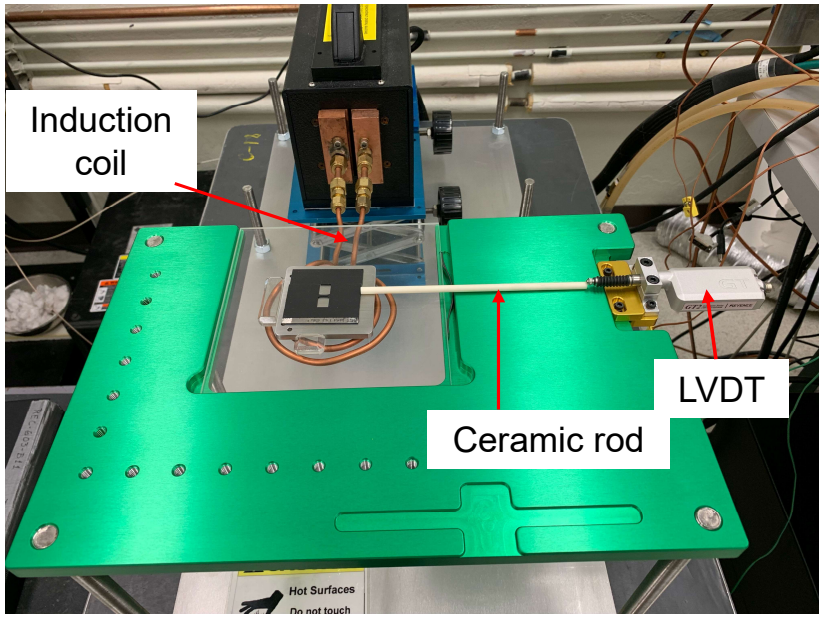


Heating of specimen

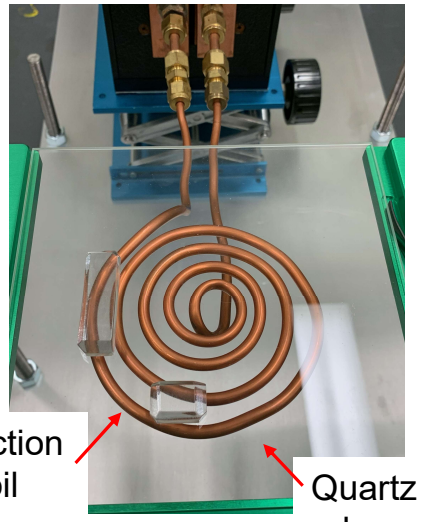
- **First version of induction coil design**
  - Large temperature gradients and ‘Hot spots’ in test articles
- **Second version of coil design**
  - No ‘hot-spots’
- **Second version of coil design + susceptor plate**
  - Improved temperature uniformity

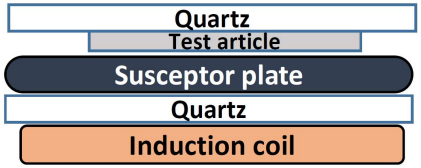
Induction Heating Setup Allowing Higher Heat Up And Cool Down Rates

Induction Test setup with susceptor plate

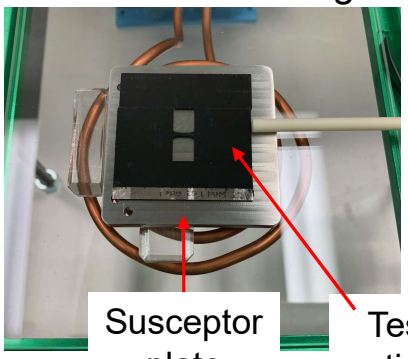


Induction coil





Induction heating

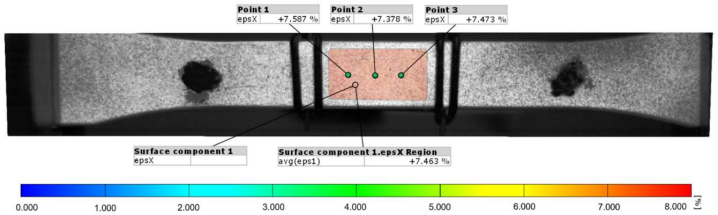


Summary

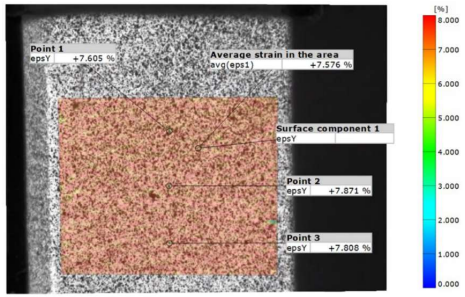
- Established flat test article design and fabrication with welded and interlocking load transfer mechanism
- Buckling is mitigated in flat sample
- Specimens could be re-used for material surveillance after cool-down to room temperature
- Speckle pattern and DIC setup are optimized
- LASER engraving technique instead of paint brushing is being adopted to apply the speckle pattern

Appendix – Validation Of DIC Setup Room Temperature Tension Test

Flat tensile specimen

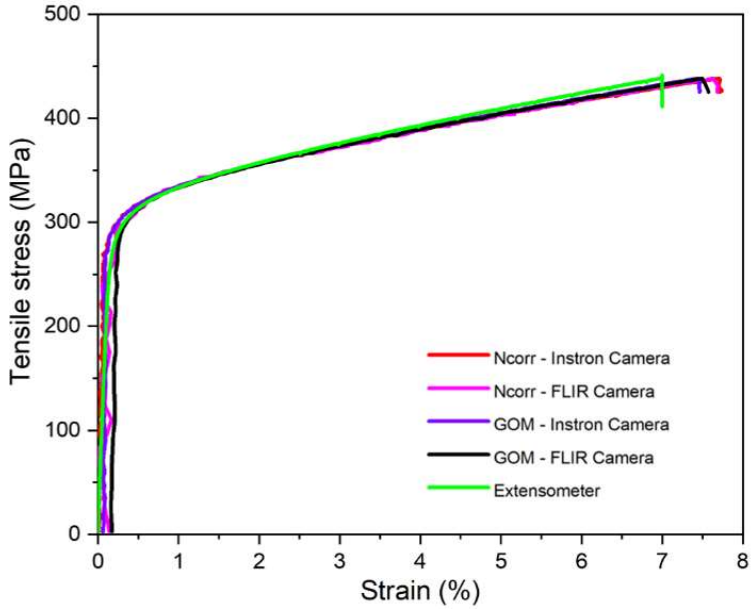


(a)

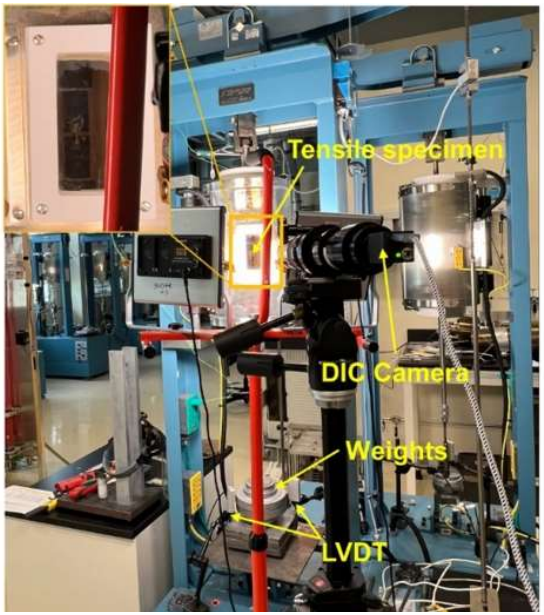


(b)

Comparison of DIC vs extensometer data

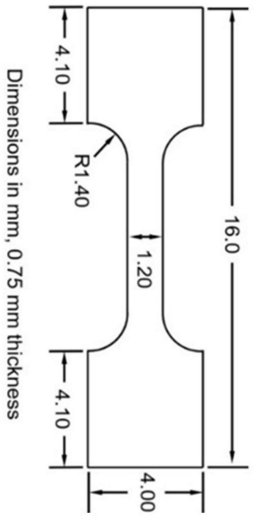


Appendix – Validation Of DIC Setup Elevated Temperature Tension Test

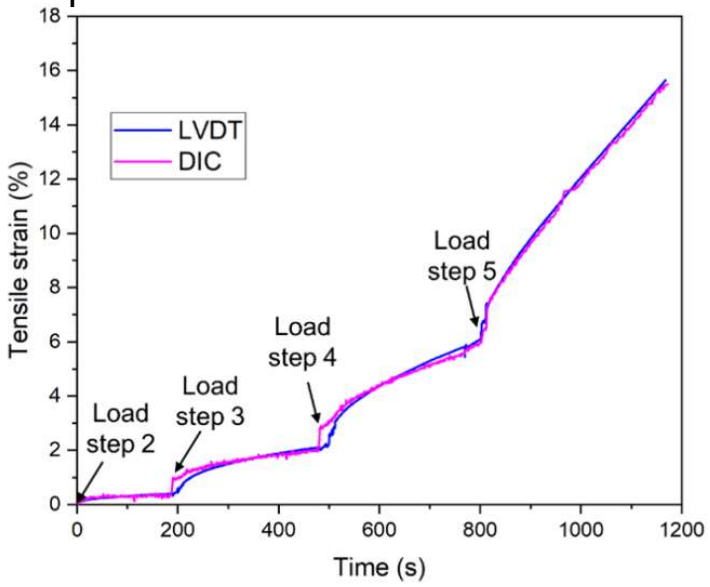


Test setup

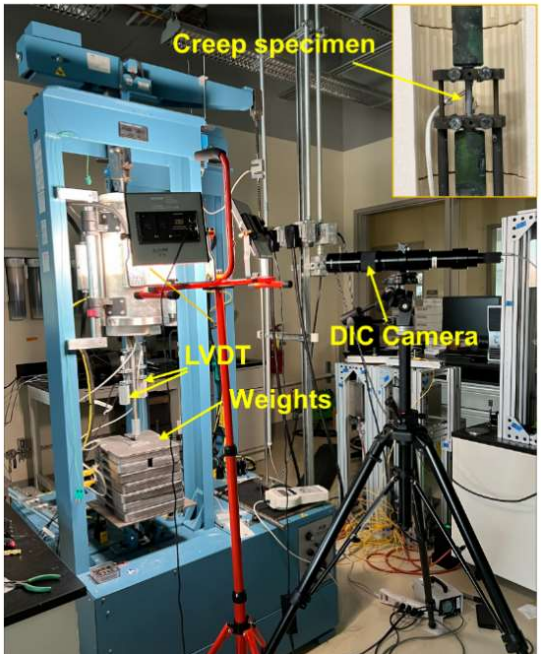
Flat tensile specimen



Comparison of DIC vs extensometer data

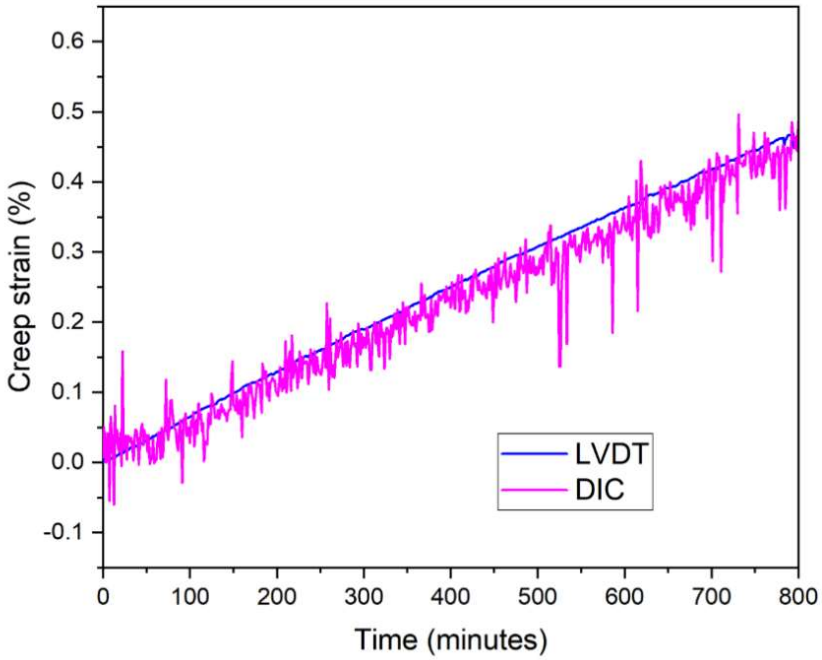


Appendix – Validation Of DIC Setup Creep Test



Test setup with standard ASTM creep sample

Comparison of DIC vs extensometer data



Thank you

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